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(WO/1990/004164) ANESTHETIC AGENT IDENTIFICATION ANALYZER AND CONTAMINATION DETECTOR

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Title: (EN) ANESTHETIC AGENT IDENTIFICATION ANALYZER AND CONTAMINATION DETECTOR
(FR) APPAREIL D'ANALYSE PERMETTANT D'IDENTIFIER LES AGENTS ANESTHESIANTS ET D'EN DETECTER LA CONTAMINATION

Abstract:

(EN) A gaz analyzer for measuring the transmission of infrared radiation through a gas mixture, determining the concentrations of the gases in the mixture, identifying one of the gases, reporting the concentration of the identified gas, and detecting contamination of the gas. The gas analyzer has a sample cell (21) for containing the gas mixture, source of infrared radiation (11), a set of specifically chosen filters, a signal processor (24), and a microprocessor (59) that computes the concentrations of the gases and implements decision logic for identifying one gas and detecting contamination of that gas. In one embodiment, a filter wheel (17) holds the filters between the source and the sample cell and there is a single detector placed downstream from the sample cell. In a second embodiment, a chopper produces an AC signal from the infrared radiation source and there are three filters, one in front of each of three detectors. An alternate embodiment measures, calculates, and reports the concentrations of three anesthetizing agents.

(FR) Appareil d'analyse de gaz permettant de mesurer la transmission de radiation infrarouge à travers un mélange gazeux, de déterminer les concentrations en gaz du mélange, d'identifier l'un des gaz, de rendre compte de la concentration du gaz identifié et de détecter la contamination dudit gaz. L'appareil d'analyse de gaz comprend une cellule échantillon (21) contenant le mélange de gaz, une source de radiation infrarouge (11), une série de filtres choisis de manière spécifique, une unité de traitement des signaux (24) et un microprocesseur (59) qui calcule les concentrations en gaz et effectue les opérations logiques pour identifier un gaz et en détecter la contamination. Dans un mode de réalisation, une roue de filtre (17) tient les filtres entre la source et la celule échantillon, et un seul détecteur est placé en aval de la cellule échantillon. Dans un deuxième mode de réalisation, un interrupteur périodique produit un

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ANESTHETIC AGENT IDENTIFICATION ANALYZER AND CONTAMINATION DETECTOR

Field of the Invention

This invention relates generally to infrared gas analyzers and more particularly to an infrared gas analyzer which identifies and quantifies anesthetic agents and detects contaminants.

Background of the Invention

Anesthetization is an inherently hazardous undertaking. Any mistakes in the procedure, while not common, can have catastrophic consequences both to the patient and to the hospital. It is thus extremely important for physicians to know what anesthetizing substances are being administered to patients, the concentrations of those substances, and whether there is contamination. The use of an incorrect anesthetizing agent, because of mislabelling or mistake, may seriously affect a patient's well-being even to the point of causing death. Agents used in incorrect concentrations are likewise dangerous, particularly when the physician must consider the varying needs of different patients. For example, a child or a particularly weak patient may require lower concentrations of anesthetizing agents than an average patient. Contamination of an anesthetizing gas is similarly dangerous to the patient's health and to the hospital in terms of liability. In spite of this, many operating theaters have no capability for identifying or measuring anesthetizing agents, or detecting contamination in the stream of gas flowing to the patient.

hile there are instruments for identifying and measuring concentrations of gases, if they are sufficiently accurate for hospital use, they are typically very expensive and bulky. If they are smaller and less expensive, they are generally not sufficiently accurate or reliable.

To promote general safety through widespread use, a device used for purposes of identification, -quantification and detection thus should be conveniently portable and relatively inexpensive. Also, because of the serious consequences of mistakes, identification and measurements must be reliable and accurate.

Identification of substances is often accomplished by mass spectrometers. These are instruments which ionize the particles of the substance (thereby giving it a positive charge) and then, by means of electric and magnetic fields, selectively deflect the particles onto a detector according to the particles' mass, thereby identifying them from their mass value. Mass spectrometer measurements are very accurate and have come into widespread use. However, a mass spectrometer of high quality is relatively expensive and typically not very portable, thus making it unsuitable for most operating theater environments.

Another method of identification is to scatter a beam of radiation off of the particles (so- called Raman scattering) , and by analyzing the scattered radiation, identify the substances present. This method, however, requires relatively high power for operation (for example, a typical instrument used for the identification of anesthetizing agents uses 3 K power supplies) . Raman scattering devices also are

relatively expensive and likely produce radio frequency interference problems. For these reasons, these devices are not particularly suitable for operating theater use.

Another type of gas analyzer uses the radiation absorption characteristics of gases in the infrared region of the electromagnetic spectrum. Many different kinds of such infrared gas analyzers are known in the art. They typically utilize an infrared source and one or more filters to produce and direct infrared radiation through an unknown gas mixture contained in a sample cell. The absorption effect of the gases on the radiation is detected and electrical signals are produced and analyzed to determine the identities and/or concentrations of the gases in the gas

mixture.

Because the absorption spectra of different gases may overlap and because some gases absorb more strongly than others, it is often necessary to limit detected wavelength intervals by means of narrow bandwidth filters. For example, the absorption band of water vapor is very wide and that of carbon dioxide is very strongly absorbing. In order to detect other gases in the wavelength intervals in which these gases absorb, filters designed or chosen for the detection of particular gases must be used. Often, these filters are placed on a filter wheel placed between the radiation source and the detector. A gas analyzer exemplifying these principles is described in U.S. Patent No. 4,692,621 to Passaro et al., and assigned to the assignee of the present invention. Passaro et al. teaches an improved infrared gas analyzer capable of high accuracy and fast response at a relatively low cost.

Another prior art infrared device for identifying and determining concentrations of anesthetizing agents includes a black-body infrared radiation source, four opto-electronic channels (one channel for each of four predetermined agents) , four filters, and a protocol for identifying specific agents. The protocol consists of taking ratios of the outputs of the four detection channels and, with knowledge of expected concentrations of agents, determining the identity of an agent by comparing the various ratios. Concentrations are determined by utilizing a normalized channel output vs. concentration graph. Such a device is manufactured by Teledyne Analytical Instruments in California.

The Teledyne device, however, is accurate only for expected concentrations of agent. Concentrations are not actually calculated and the Teledyne device does not detect contamination.

Some common anesthetizing agents and their trade names are enflurane (ethrane) , isoflurane (forane) , and halothane. An anesthesized patient's inhaled and exhaled breath will likely contain these gases and also carbon dioxide, water vapor, nitrous oxide, and oxygen.

The absorption bands of the anesthetizing agents forane, ethrane, and halothane strongly overlap one another and have similarly shaped absorption curves. Halothane also is very weakly absorbing and thus difficult to measure. Further, the concentrations of these agents in typical anesthetizing dosages is very low (5% for forane and ethrane and .8% for halothane) , making them even more difficult to measure.

These facts, together with the presence of carbon dioxide and water vapor absorption bands in the same wavelength region, make identification and measurement extremely difficult.

This difficulty is compounded by a source of error common to gas analyzers called "zero-drift." Zero drift may cause erroneous infrared radiation transmission values which produce incorrect identification or concentration results. Zero drift can be produced by contamination in the measuring system, shifts in the output of detectors (which are inherent in many types of detectors) , and temperature changes in the measuring system. Some gas analyzers, such as U.S. Patent No. 4,692,621 to Passaro et al., compensate for zero-drift by using reference filters to provide a reference channel against which the measured signals may be compared. Since the reference channel utilizes the same optical path (except for the filter) , the effects of zero-drift may be compensated for to some extent. Zero-drift, however, is still a potential source of serious error because of differences among the various filters and electro-optical channels in the measuring instrument. These errors must be considered if reliable and accurate measurements are to be made.

Accordingly, it is an object of the present invention to provide a conveniently portable, low-cost anesthetizing agent identification analyzer and contamination detector.

It is a further object of the present invention to accurately identify one of the anesthetizing agents ethrane, forane, and halothane in the inhaled and exhaled breath of patients undergoing anesthesia.

It is another object of the present invention to detect and report the presence of contamination of the identified anesthetizing agent.

It is yet a further object of the present invention to measure and continuously report in real time the concentrations of the identified anesthetizing agent.

It is still a further object of the present invention to identify, determine, and continuously report the concentrations of all of the anesthetizing agents ethrane, forane, and halothane.

Summary of the Invention

The present invention is a gas analyzer apparatus for measuring infrared transmission through a mixture of gases, determining the concentrations of those gases, identifying one of the gases, reporting the concentration of the identified gas, and detecting contamination of the gas. The gas analyser comprises a sample cell for containing the gases, a source of infrared radiation, a set of specifically chosen filters on a filter holder, a signal processor, and a microprocessor that computes the concentrations of the gases and implements decision logic for identifying one gas and detecting contamination of that gas. In one embodiment, a filter wheel holds the filters between the source

and the sample cell and there is a single detector placed downstream from the sample cell. In a second embodiment, a chopper produces an AC signal from the infrared radiation source and there are three filters, one in front of each of three detectors. An alternate embodiment measures, calculates, and reports

the concentrations of three anesthetizing agents.

Brief Description of the Drawings

Figure 1 is block diagram of an infrared gas analyzer according to the present invention.

Figure 2 illustrates the transmission curves versus wavenumber of ethrane, forane, halothane and three filters utilized in an embodiment of the present invention.

Detailed Description of the Invention

The present invention is a conveniently portable, inexpensive infrared gas analyzer system utilizing a combination of filters chosen for their discriminability, sensitivity, and availability at relatively low cost. These filters are part of an infrared gas analyzer system which is capable of accurately measuring infrared transmission through gases, and includes a microprocessor-embedded mathematical algorithm for calculating agent concentrations, identifying anesthetizing agents, and detecting the presence of certain contaminating gases.

A simplified block diagram of the system of the present invention is shown in Figure 1. A gas analyzer 10 comprises a sample cell 21, an infrared source 11 which produces and transmits radation through sample cell 21 via a filter wheel 17 having at least one filter thereon. Filter wheel 17 rotates to successively interpose filters between source 11 and sample cell 21. A motor 19 and a belt drive 20 operate to rotate filter wheel 17 under the control of a signal processor 24. Infrared radiation passing through

sample cell 21 is detected by detector 15 and an electrical signal is produced which is representative of the intensity of the infrared radiation by signal processor 24. Signal processor 24 is described in detail in U.S. Patent No. 4,692,621 to Passaro et al. which is hereby incorporated by reference. Sample cell 21 has an inlet connection to a tube 23 which is connected to a valve 51 which regulates the intake between the ambient air passing through a scrubber 53 and a patient's airway. Valve 51 is controlled by signal processor 24. Sample cell 21 has an outlet connection to an exhaust tube 18 which is connected to a pump 16 which is itself connected by tubing to an oxygen (O_2) sensor 49 and is controlled by an electrical connection to signal processor 24. Gases inhaled by the patient take the "to patient airway" path and gases exhaled by the patient take the "exhaust" path. Also electrically connected to signal processor 24 is an ambient temperature sensor 47. Electrically connected to signal processor 24 is a communications board 55 for communicating between signal processor 24 and an outboard computer 57 and host computer 59. Host computer 59 reports the data regarding agent identification, agent concentration, and contamination detection.

In a first embodiment of the present invention, filter wheel 17 has three interference type filters which are selected to pass narrow bands of infrared radiation, each having different band centers at predetermined wavelengths, to provide three measuring signals, plus a fourth filter which is added to provide a reference signal. A fifth segment of filter holder 17 may be used to block radiation from sample cell_21 so that the associated signal may be used to measure background noise from extraneous

radiation, electronics, detector null, and any other optical or electronic noise. A more detailed description of a similar filter system is given in the above-referenced U.S. Patent No. 4,692,621 to Passaro et al.

In a second embodiment of the present invention (not shown in Figure 1) , there is a chopper for producing a square wave AC signal between source 11 and sample cell 21. Instead of a single detector 15, there are three detectors, one for each gas of interest. Disposed between sample cell 21 and the three detectors is a holder for the three filters. Each of the three detectors has a filter in front of its receiving end.

The difficulty of isolating the absorption bands of the anesthetizing agents forane, ethrane, and halothane is indicated in Figure 2 showing the transmission curves of these agents superimposed with the transmission curves of three exemplary filters. These curves are measures of the amount of infrared radiation from infrared source 11 (Figure 1) that is transmitted through the agent gases contained in sample cell 21 and detected by detector 15 as a function of wavenumber (the reciprocal of wavelength) . The greater the transmission, the less the absorption by the particular gas. Curve 201 is the transmission curve for forane, curve 202 is for ethrane, and curve 203 is for halothane. It can be seen that these curves are strongly overlapping, that forane and ethrane have very similar transmission curve shapes, and that halothane is very weakly absorbing. The presence of carbon dioxide and water vapor absorption bands in the same wavelength region make identification and measurement even more difficult. Filters 210, 220, and 230 are

chosen for discriminability sufficient to distinguish among the gases, for sensitivity to allow measurement of concentrations of the gases to a precision sufficient for identification, and because they are relatively inexpensive. Such filters are available from, among others, Barr Associates of Massachusetts. The filters utilized in one

embodiment of the present invention have the following specifications (in wavenumber units) at the operating temperatures of the filters in the analyzer:

Filter Center and Tolerance Bandwidth

210 3038 ± 5 33 ± 5 220 3012 ± 8 46 ± 5

230 2998 ± 5 35 ± 5

In another embodiment of the present invention, the filters have these specifications (in wavenumber units) again at the operating temperatures of the filters in the analyzer:

Filter Center and Tolerance Bandwidth

210 3047 ± 5 33 ± 5

220 3009 ± 8 46 ± 5

230 30i7 ± 5 35 ± 5

Various other combinations of filters will be apparent to those skilled in the art and are utilizable without departing from the scope of the present invention.

In operation, returning to Figure 1, inhaled and exhaled gases from a patient are supplied to sample cell 21 through tubes 23 and 18 respectively. Source

11 emits infrared radiation in the wavelength region of interest, which radiation passes through the filters in filter wheel 17 which is rotated to successively interpose the desired filter in the radiation beam by means of control signals from signal processor 24. The transmitted radiation is detected by detector 15 which converts the measured transmission into electrical signals for processing by signal processor 24. Various operating conditions sensed by appropriate sensing devices, only some of which are illustrated, are applied to signal processor 24. For example, ambient temperature and oxygen are sensed by ambient temperature sensor 47 and 0_2 sensor 49 respectively and fed into signal processor 24 for inclusion in the data stream if desired.

The operation of the second embodiment is similar to that described above except that the chopper chops the radiation from source 11 and the AC signals pass through sample cell 21, and the three filters in front of the three detectors.

The transmission values and other data are then fed by signal processor 24 to communications board 55 which controls the data to be sent to either outboard computer 57 or host computer 59. Outboard computer 57 monitors the optical transmission values. When transmission is detected below (or absorption is above) a certain threshold level, outboard computer 57 initiates an agent identification algorithm (to be described in detail below) . Agent concentrations are calculated (using a method to be described in detail below) and compared with threshold values to determine which of the following is true: (1) an agent is not present at levels above the threshold level, (2) an agent is present at a level above the threshold level

and that agent is identified, or (3) there is contamination by another agent. Once identified, the appropriate one of the set of three filters is interposed by filter holder 17 and the concentration of that agent is determined by a microprocessor-based table look-up procedure of concentration versus transmission. This is done by outboard computer 57 which then continuously reports the concentration of that identified agent in approximately 14 msec intervals. This information is then transmitted along with the identity of the agent in the gas and the calculated concentration of that agent to host computer 59 which reports the data for display.

In an alternate embodiment, for those cases where all three agents forane, ethrane, and halothane may be present, the present invention can calculate the concentration of each agent and report those concentrations. This embodiment requires a co- processor as part of outboard computer 57 to speed up the measuring, calculation, and reporting functions. The essential procedure is identical to that described below.

Before operation, gas analyzer 10 is calibrated at the factory to determine the absorption coefficients for the particular gases of interest. In the calibration procedure, three binary gases each consisting of one of the agent gases (forane, ethrane, or halothane) and a carrier gas (usually nitrogen) are passed through sample cell 21. Each filter in filter holder 17 is interposed successively and the absorption (transmission) of each of the agent gas/filter combinations is measured. To calculate the absorption coefficients, the following known procedure is utilized with the understanding that other numbers of agents and

filters could be used without departing from the scope of this invention.

The absorption (A) and transmission (T) is given by

T = (1 - A) = exp(-kc) (I)

where k is the absorption coefficient and c is the concentration of the agent. For each combination of agent and filter, the transmission τ^ is given by

T-LJ = exp(-kijCj) (2)

where i = 1, 2, 3 designates each filter and j = 1, 2, 3 designates each agent. Now, ci is known because a known concentration of each agent gas is successively run through sample cell 21, τ^ is measured by gas analyzer 10 in the manner described above, and equation (2) is used to calculate k^, the absorption coefficents for each combination of agent gas and filter. The absorption coefficients are stored in outboard computer 57 for use in the subsequent concentration calculations.

In operation of an embodiment utilizing three filters only (no reference filter) , when a gas containing two or more agents is to be measured, the radiation transmitted by each filter can be approximated by

r = * exp(-$k_{i2}c_2$) * exp(-$k_{i3}c_3$) (3)

or

$\tau_{\pm}$ = exp-($_{ilCl}$ + $k_{i2}c_2$ + $k_{i3}c_3$) (4)

which can be written as

- In TJ = $k_{il}{}^{c}l$ + $k_{i2}{}^{c}2$ + $k_{i3}{}^{c}3$ (5)

The set of equations represented by equation (5) can be expressed using matrix algebra as

- In T = K * c (6)

where τ_ and c are the column vectors { T ^} and (c^ } and

is the 3 x 3 matrix (^ -i} which is just

Ecjuation (6) can be solved using the inverse matrix K -I to yield the concentrations c, namely

The procedure described above is a first order approximation. A better approximation is produced using a set of three filters and a reference filter which produces negligible interference. The transmissivities of the four filters may be represented using Beer's Law and mathematical curve-fitting techniques for experimental concentration/transmission data, all of which techniques are well known. Using

this approach, those skilled in the art will appreciate that a set of four non-linear equations may be produced. These may be solved using a suitable algorithm incorporated in outboard computer 57 of the present invention for the gas concentrations c_f, c_e, and c_h, and the non-interfered reference transmission T_{ref}. The algorithm may incorporate Newton's method of numerical solution, as is known in the art.

In this way, the concentrations of each of the anesthetizing agents, forane, ethrane, and halothane, can be calculated. In one embodiment of the present invention, these concentrations may be reported directly to a display by a co-processor as part of outboard computer 57.

The procedures described previously generate three gas concentrations, one each for forane, ethrane, and halothane. If, however, the measured filter transmissions t^ are inaccurate (due to zero-drift) there will be a corresponding error in the calculated agent concentrations. In instruments of this kind, there are also the well-known span errors (when there are actual measurements taken with unknown gases in sample cell 21) , and errors from noise which is inherent in detecto. 15. The cumulative error has been determined empirically and has been used to establish the threshold for identification and detection.

^{c}e = ^{c}pe + ^{dc}pe

^{c}h = ^{c}ph + ^{dc}ph

where $c_{D-\_.}$ = the calculated concentration of gas j

XTJ

dc_j = the maximum error of the calculated concentration of gas j .

The errors represented by dc_-_j form the detection thresholds for each gas. The errors are different for each analyzer, depending on many different factors contributing to variations in analyzer performance. The identification software of the present invention computes (c_-; - dc_A for each gas and then implements the following decision logic:

(a) If (c_{pj} - dc A < 0 for each gas, then UNDETERMINED

(b) If (c -: - dc A > 0 for exactly one gas, then SINGLE GAS

(c) If (Cp-j - dCpA > 0 for more than one gas, then CONTAMINATED

Decision (a) means that measured and then calculated concentrations which are less than the maximum errors represented by dc_^ are not sufficiently large for a determination.

Decision (b) indicates the presence of a single, significantly different from zero, concentration which serves to identify the agent.

The first time the analyzer identifies the presence of an agent, its status is changed from "no agent identified" to "agent identified". The analyzer then reports out the agent's concentration after calculations, as described above, are done automatically.

Contamination decision (c) operates as

follows: If only one anesthetizing agent is being used and the derived concentrations of two or more agents are larger than the assigned measurement uncertainty, this indicates that there is contamination. If the agent is uncontaminated, then two of the three concentrations derived will be close to zero. Because of the relatively low concentrations of anesthetizing agents typically used (5% for forane and ethrane) 8% for halothane, any agent contaminant will likely be at very low levels.

Any other substances having absorption bands in the wavelength region covered by the present invention may be detected as a contaminant providing the concentration is above the detection threshold. This would include many hydrocarbon-based substances which have absorption bands in the region and includes alcohol and acetone which may be present in operating theaters. A contaminant in the wavelength region of the anesthetizing agent in use will also be detected in the form of greater than expected concentrations of that agent.

The above description of the present invention has been made with reference to an infrared gas analyzer for the identification and quantification of anesthetic agents and the detection of contamination. It will be apparent to those skilled in the art that the present invention is applicable to a much larger class of gas analyzers.

Accordingly, there has been described herein an accurate, fast-response time, conveniently portable infrared gas analyzer suitable for operating theater use. Various modifications to the present invention will become apparent to those skilled in the art from

the foregoing description and accompanying drawings and the present invention is to be limited solely by the scope of the following claims.